

# The vertical structure of relative humidity and ozone in the tropical upper troposphere

Intercomparisons among *in situ* observations,  
A-Train measurements and large-scale models

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# Motivation

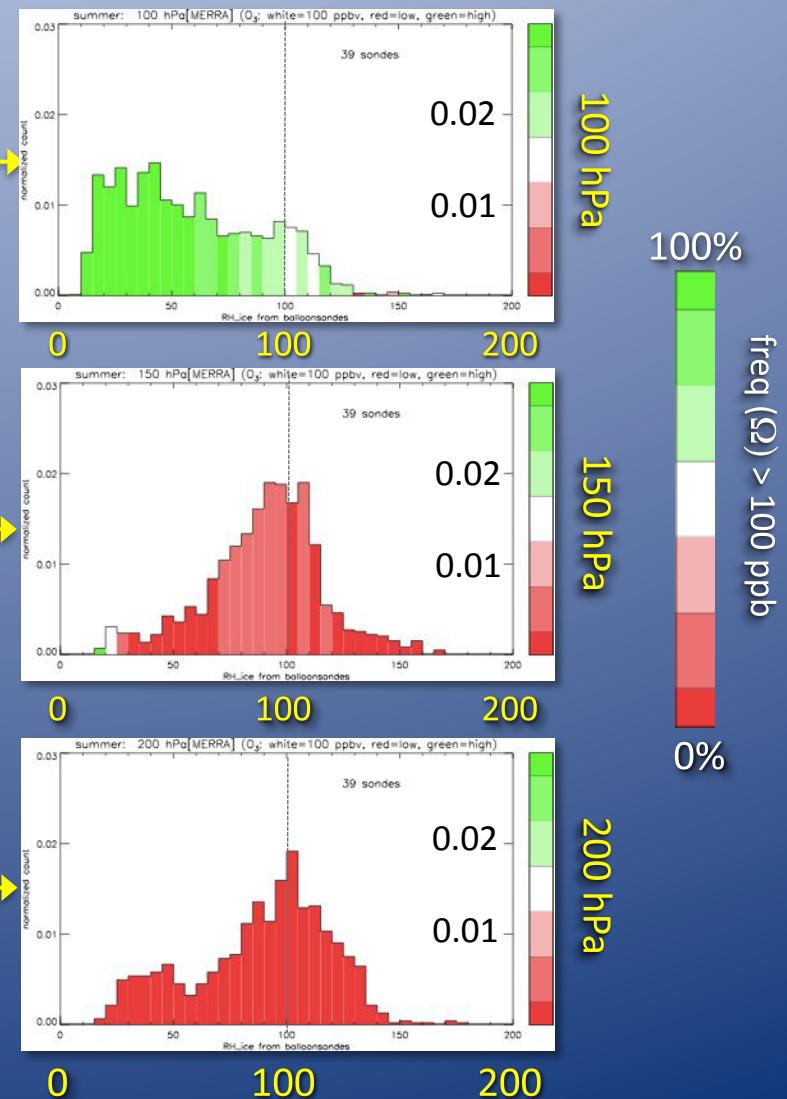
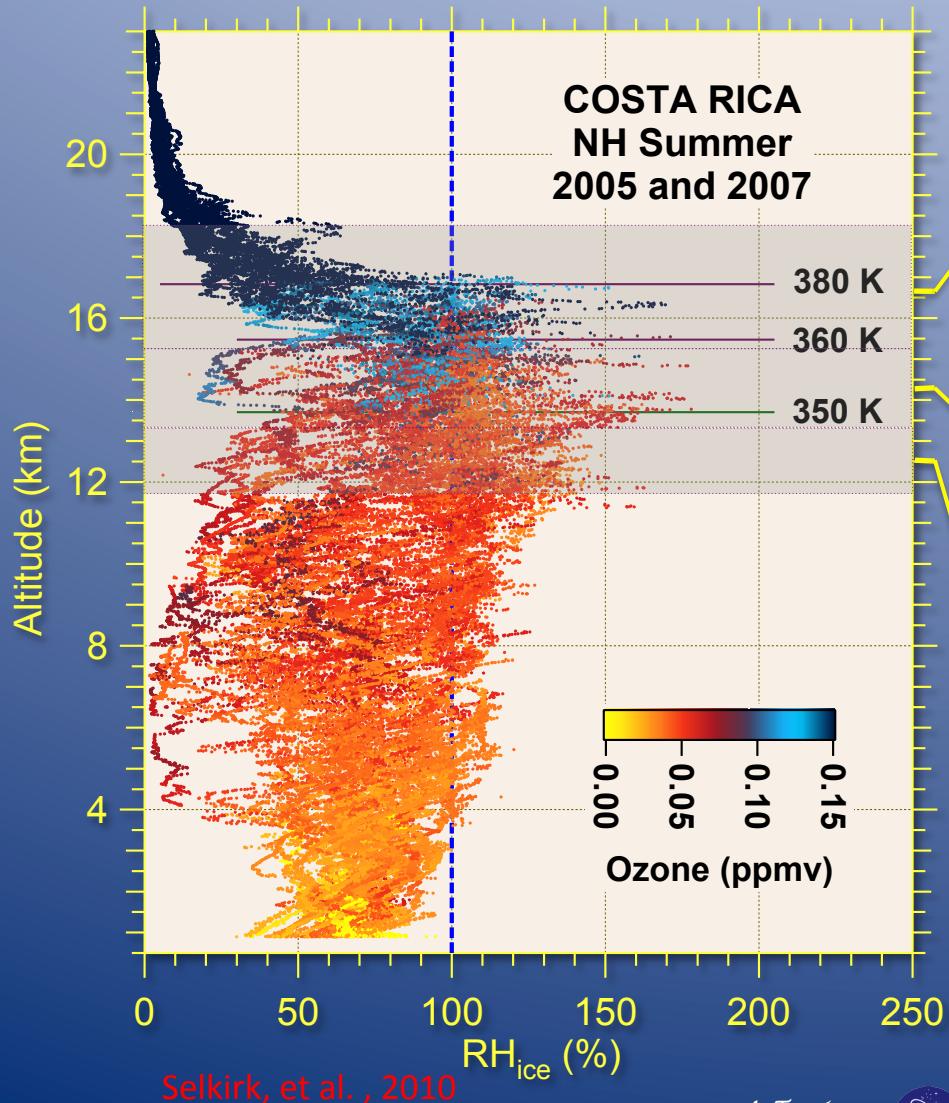
**Ice supersaturation is a sensitive indicator of upward motion and is an important piece of the puzzle of the UT water vapor budget and formation of cirrus clouds**

Towards a unified perspective through inter-comparison of frequency distributions of  $\text{RH}_{\text{ice}}$  and  $\text{O}_3$  in the tropical upper troposphere from:

- ✓ Balloon sonde (**CFH**) and aircraft (**MOZAIC**) water vapor measurements
  - suggest supersaturation is a common feature in the tropical UT, but coverage limited
- ✓ A-Train measurements such as **AIRS** and **MLS** - provide global/synoptic views of relative humidity fields, but vertical resolution is limited.
- ✓ Large-scale models, e.g. **GEOS-5 MERRA reanalysis** and the free-running **GEOS CCM**, provide large-scale physical context, but representation of moist physics is a major challenge.

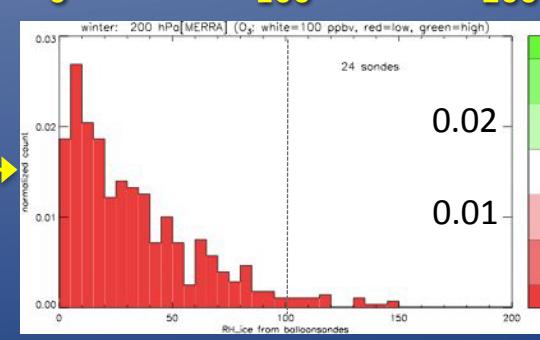
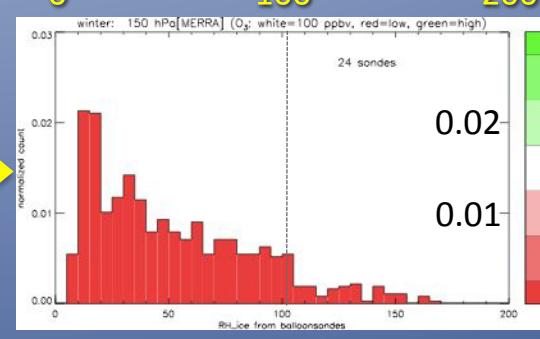
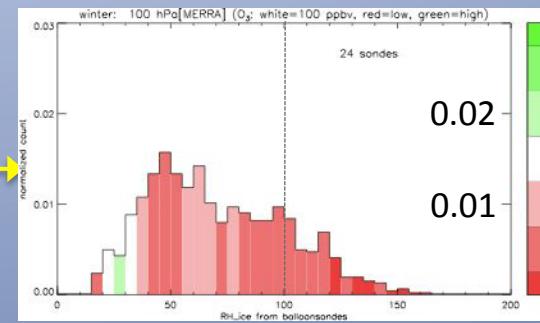
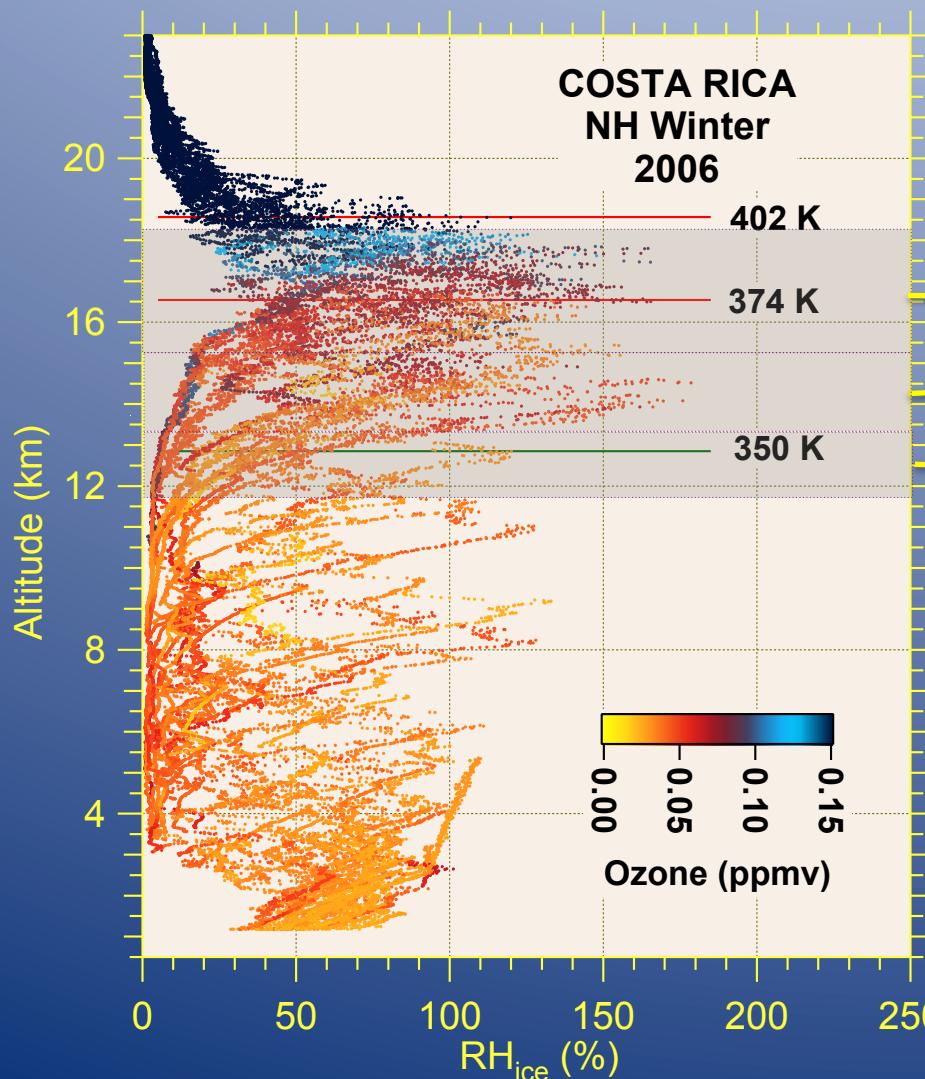
# Balloon sonde (CFH) RH<sub>ice</sub>

## Northern summer/ITCZ



# Balloon sonde (CFH) RH<sub>ice</sub>

## Northern winter/dry season



100 hPa

150 hPa

200 hPa

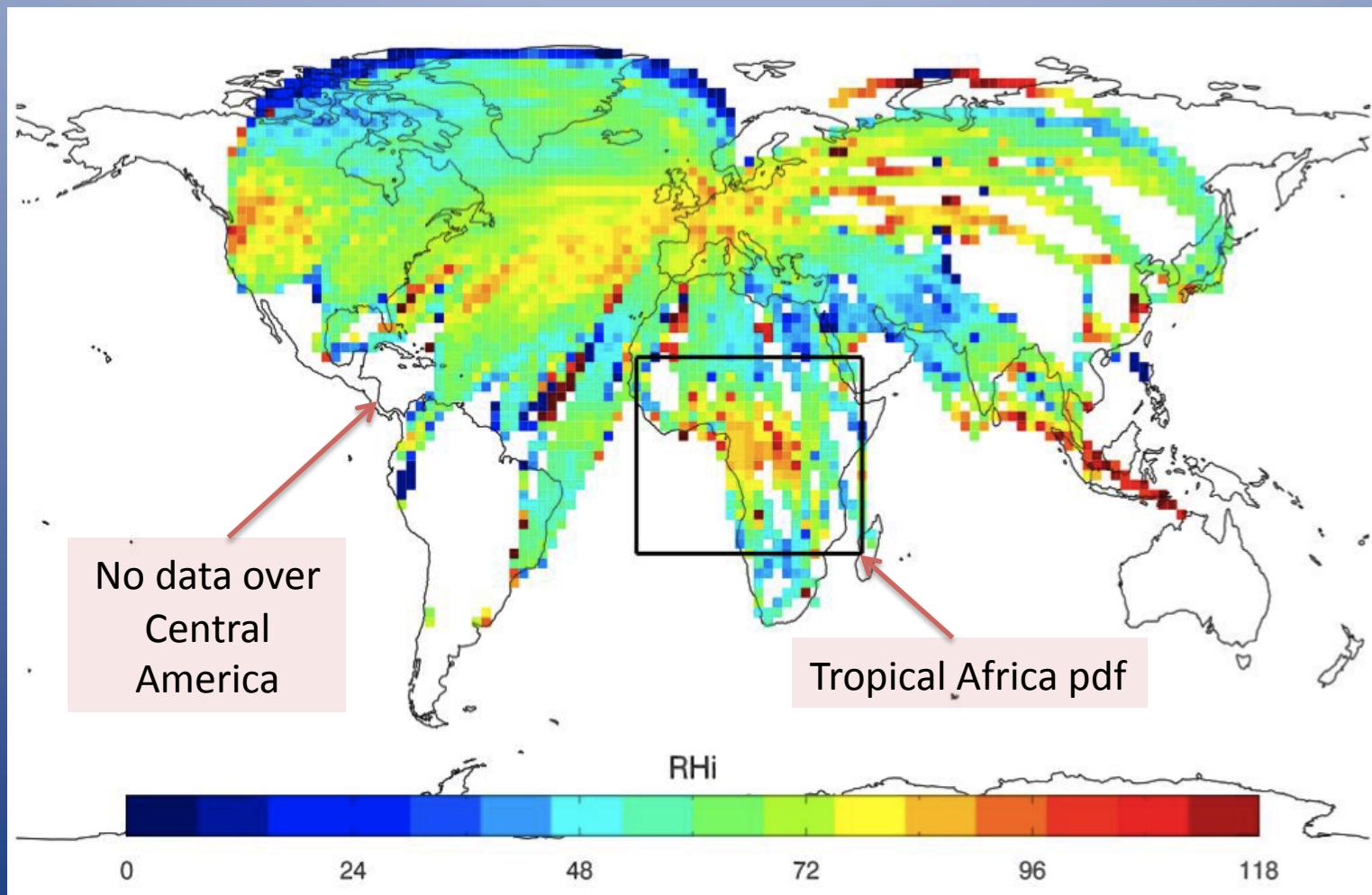
freq ( $\Omega$ ) > 100 ppb

100%

0%

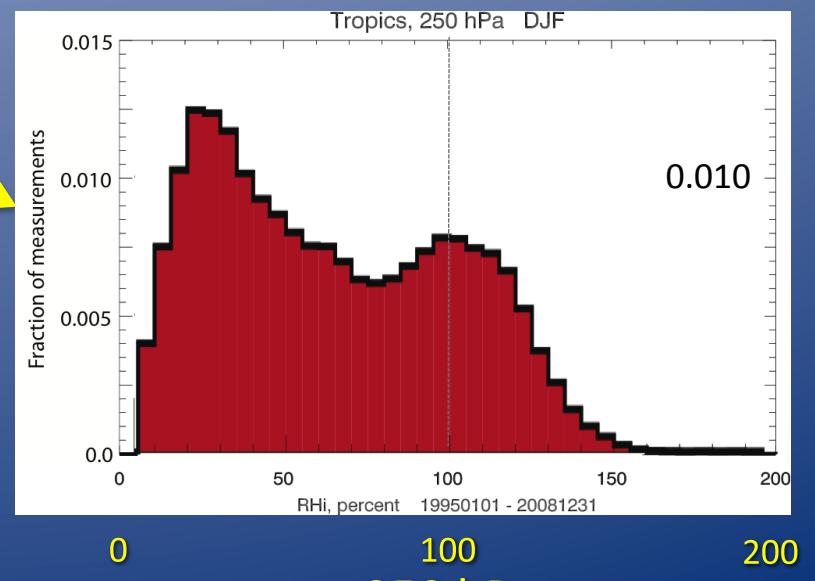
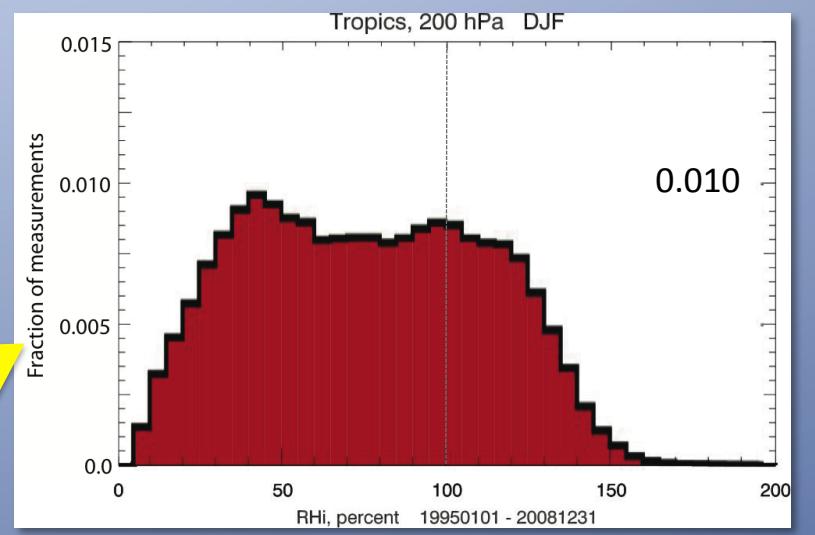
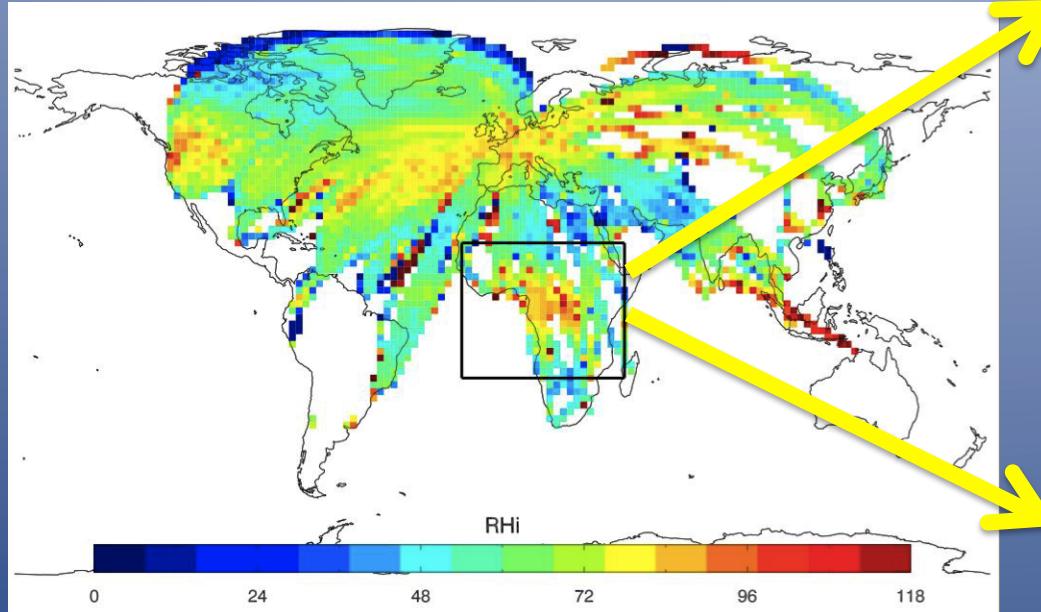
# MOZAIC (*in situ*) RH<sub>ice</sub>

1995-2008, 250 hPa



# MOZAIC (*in situ*) RH<sub>ice</sub>

1995-2008  
Tropical Africa (DJF)



# **Summary of *in situ* Observations**

## **Costa Rica sondes - Northern winter – dry season**

- Substantial supersaturation in tropopause saturation layer (TSL; 125-70 hPa) while minimal below
- Limited penetration of high ozone below TSL

## **Costa Rica sondes - Northern summer – within ITCZ**

- Substantial supersaturation from TSL down to 250 hPa layer (not shown)
- Penetration of high ozone down to ~350 K level

## **MOZAIC – Tropical Africa (DJF and JJA)**

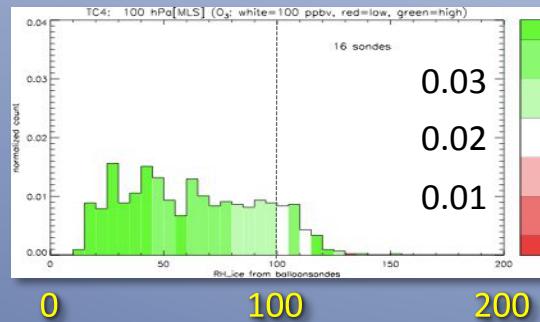
- Substantial supersaturation, increasing with height

# Northern Summer RH<sub>ice</sub>

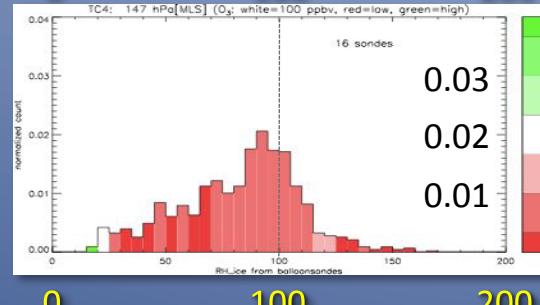
Costa Rica Jul/Aug 2007 [TC4]

CFH  
RH<sub>ice</sub>

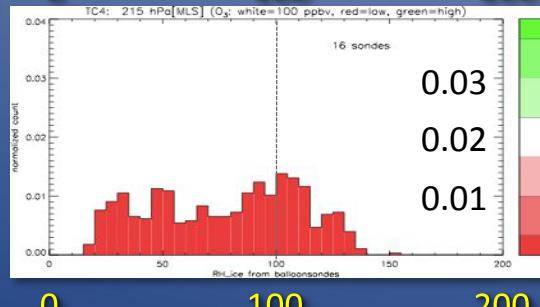
16 launches



100 hPa

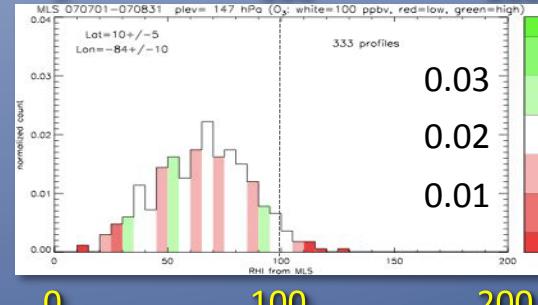
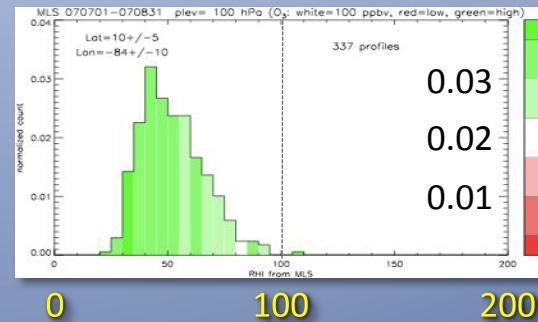


147 hPa

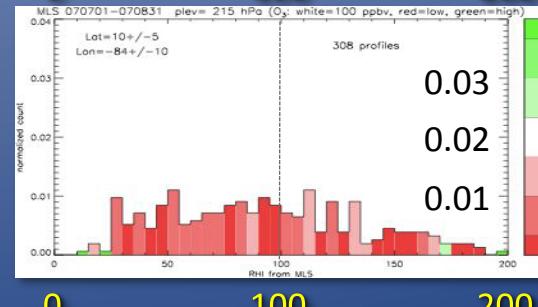


215 hPa

CFH at San José, 10°N, 84°W



MLS  
RH<sub>ice</sub>  
333 profiles



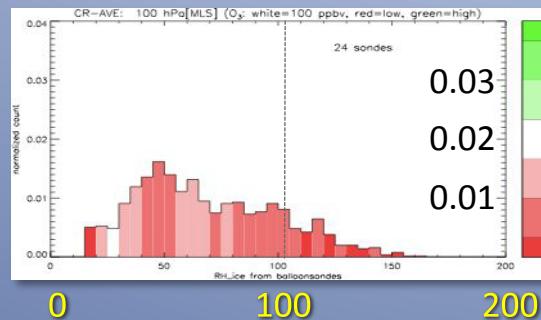
MLS 10°N±10°, 84°W±10°

# Northern Winter RH<sub>ice</sub>

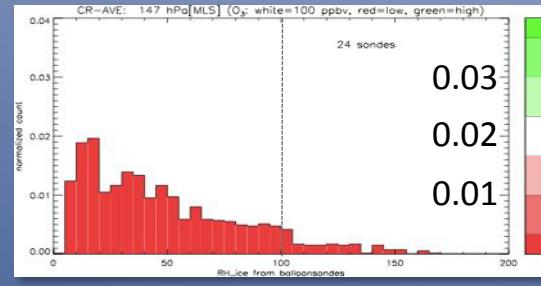
Costa Rica Jan/Feb 2006 [CR-AVE]

CFH  
RH<sub>ice</sub>

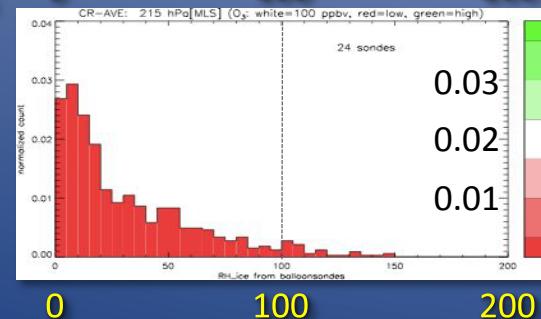
24 launches



100 hPa

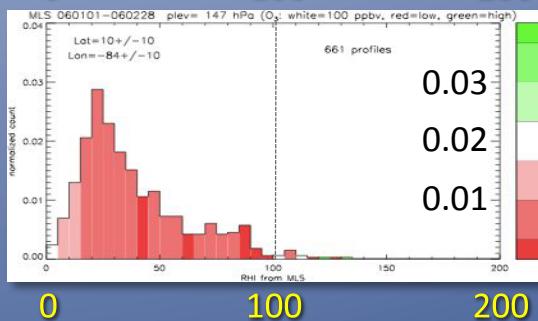
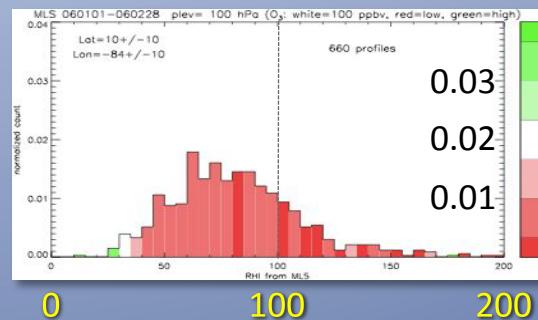


147 hPa

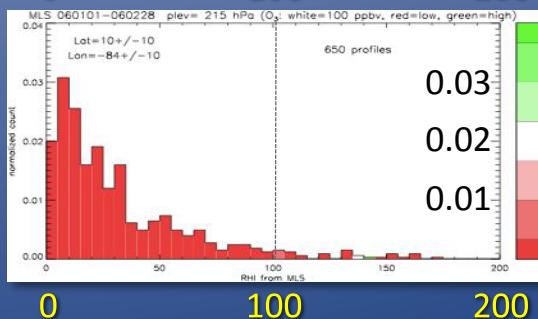


215 hPa

CFH at San José, 10°N, 84°W



MLS  
RH<sub>ice</sub>  
650 profiles

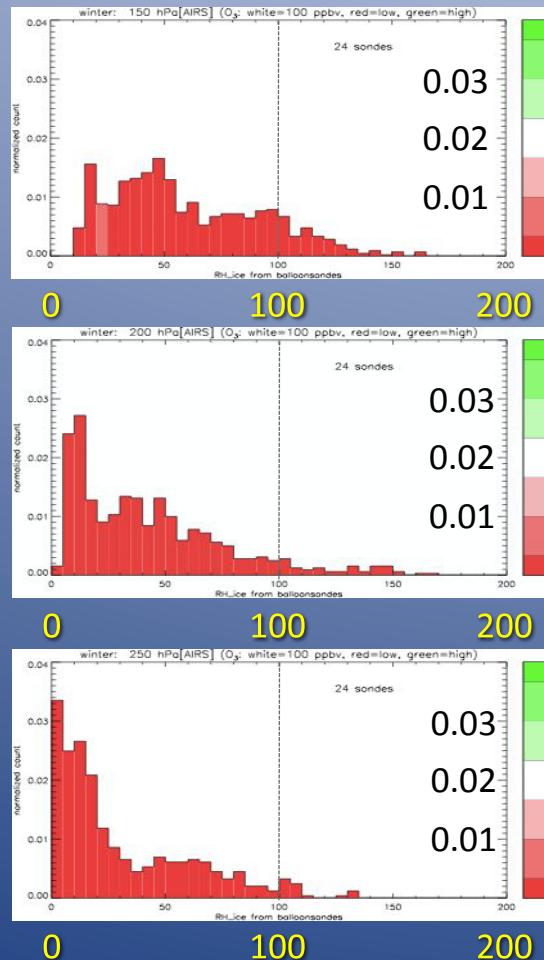


MLS 10°N±10°, 84°W±10°

# Northern Winter RH<sub>ice</sub>

Costa Rica Jan/Feb 2006 [CR-AVE]

CFH  
RH<sub>ice</sub>  
24 sondes

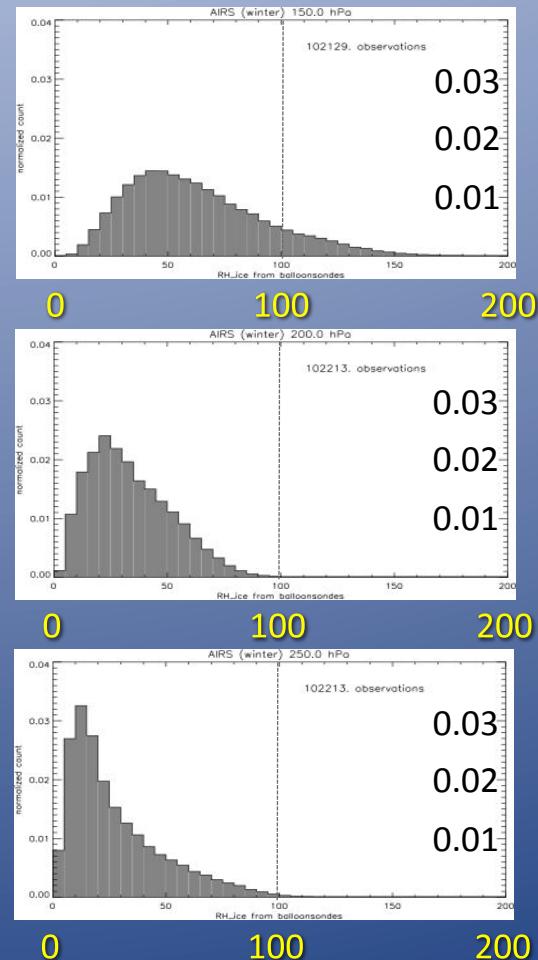


125 hPa

175 hPa

225 hPa

CFH at San José, 10°N, 84°W

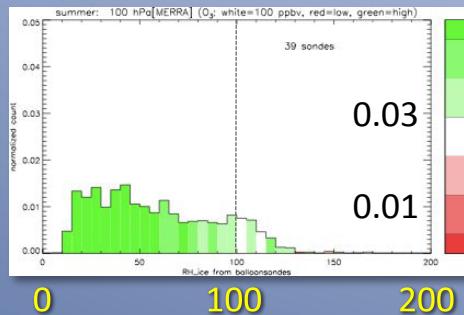


AIRS  
RH<sub>ice</sub>  
 $>10^5$  FOVs

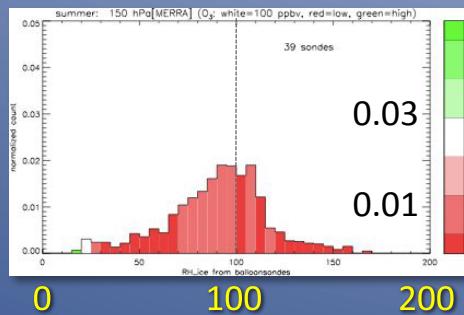
AIRS 10°N±10°, 84°W±10°

# Costa Rica sondes vs. GEOS-5 – NH Summer

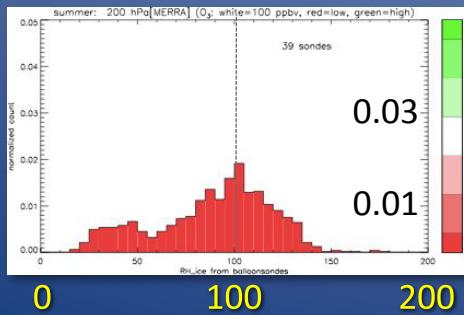
CFH/ECC sondes



100  
hPa

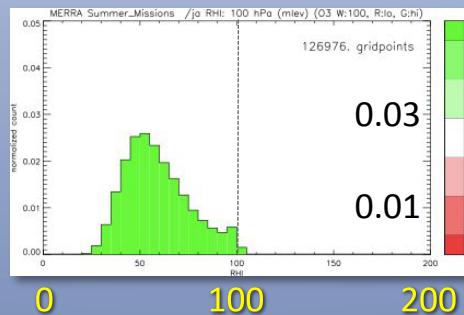


150  
hPa

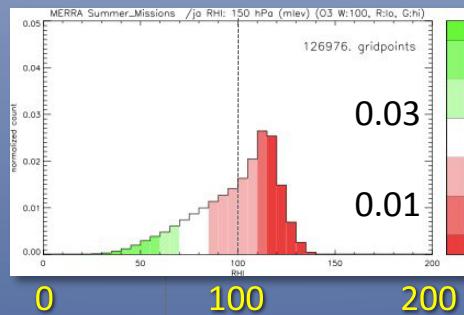


200  
hPa

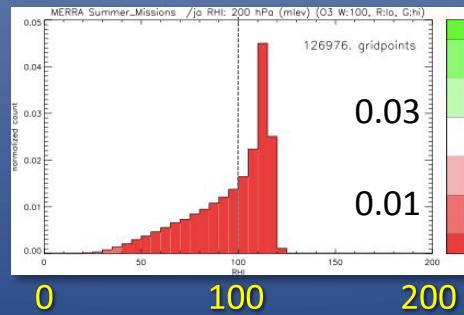
MERRA  
Reanalysis



100  
hPa

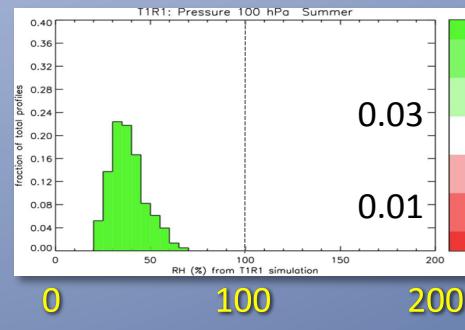


150  
hPa

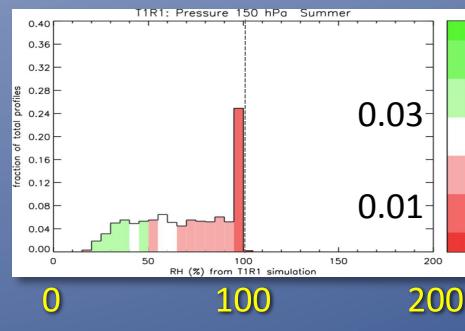


200  
hPa

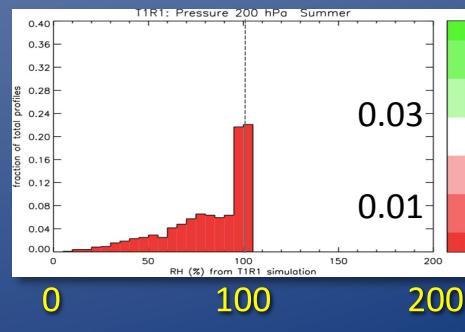
GEOS CCM



100  
hPa



150  
hPa



200  
hPa

# Summary and Conclusions

## Sondes at Costa Rica:

### Summer – regional convection

- ✓ Supersaturation common above 10 km
- ✓ High ozone events penetrating down to ~350 K

### Winter – dry season

- ✓ Supersaturation and high ozone frequent only in Trop Saturation Layer

## Sondes vs. MLS and AIRS

- ✓ MLS RH<sub>ice</sub> pdfs agree well with sondes in winter, with supersaturation near tropopause, but not in summer
- ✓ AIRS has reasonable dry season pdfs, but questionable up high due to vertical resolution

## Sondes vs. GEOS-5 – convective season

- ✓ MERRA: PDF vertical structure about right despite limitations in model moisture physics and climatological WV in stratosphere
- ✓ GEOS CCM: moisture physics limits RH to 100%
- ✓ TTL ozone too high in both - insufficient convective transport to TTL

# Some opportunities going forward

## SONDES:

- ✓ Link to particle/ice measurements: CALIPSO; MLS IWC; aerosol sondes (ETH COBALD)
- ✓ Continue ongoing sonde programs (Costa Rica) to gain greater seasonal and interannual coverage

## AIRS and MLS:

- ✓ For validating AIRS V6, extend Vaisala RH database into UT using CFH-based corrections developed by Miloshevich et al.
- ✓ More AIRS and MLS-coincident sonde launches in the tropics

## GEOS CCM:

- ✓ Validate with sondes, MLS and AIRS
- ✓ Changes to convective scheme to deepen convective mass flux

## ATTREX ballooning:

- ✓ Global Hawk EV-1 mission - Guam, Winter 2013 and 2014; Darwin, Summer 2014
- ✓ Opportunity to combine intensive tropical UT soundings with in situ and remote sensing aircraft measurements together with A-Train and NPP measurements